NATIONAL BUREAU OF STANDARDS REPORT

10 544

MECHANICAL PROPERTIES OF PAPER HONEYCOMB FOR USE IN MILITARY SHELTERS

For

U. S. Army Natick Laboratories

Natick, Mass. 01760

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ERRATA

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In the comparison of shear strengths from the plate and the flexural test methods an error was made in the statements. This error is obvious from the data especially in Figure 11.

To correct this error make the following changes:

1. One Page 23, Section 5.6, change the second sentence to read, "The data of Figure 11 shows that the plate method would develop slightly lower average shear strength values (7%) than the flexural method." (The words flexural and plate are interchanged.)
2. On Page 25, Section 6, Conclusion 8, interchange the words flexural and plate.

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NBS

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ABSTRACT

Mechanical Properties of Paper Honeycomb
for Use in Military Shelters

by

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The kraft paper honeycombs produced by four manufacturers were evaluated with respect to the requirements stated in Military Specification, MIL-H-20140A. The variables included unit weight, moisture content, thickness and manufacturer. The properties determined were strength (compressive, shear, and tensile), shear modulus and water migration.

It was found that the strength properties are proportional to the unit weight, but that the properties varied with the specimen thickness, moisture content and even the test method.

Table of Contents

NOTATION

d = Unit weight of honeycomb (density), pcf

f_c = Flatwise compressive strength, psi

f_t = Flatwise tensile strength, psi

G = Shear modulus, psi

- G_p = By plate shear method
- G_f = By flexural shear method

(L) or (W) = A property in the "L" or "W" direction*

S = Shear strength, psi

- S_p = By plate shear method
- S_f = By flexural shear method

t_c = Honeycomb core thickness, in

*"L" direction refers to the direction parallel to the ribbons of paper from which the honeycomb is made. (See Figure 1)

"W" direction refers to the direction perpendicular to the ribbons.

MECHANICAL PROPERTIES OF PAPER HONEYCOMB FOR USE IN MILITARY SHELTERS

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1. Introduction

1.1 Objective

At the request of the General Equipment and Packaging Laboratory of the Army Natick laboratories the Structures Section, Building Research Division, of NBS undertook an evaluation of commercially available paper honeycombs.

The primary objective of the evaluation was to determine the physical properties of the various honeycombs promoted for use in the Military hard-shelter programs.

A corollary objective was to provide data suitable for use by Military Standardization groups in updating MIL-H-2104A, "Military Specification for Paper Base, Structural Honeycomb Materials."

A secondary objective was to evaluate the methods used in determining the physical properties of honeycomb and of panels made from honeycomb.

1.2 Background

Honeycomb material, suitable for use as sandwich panel cores, can be made of virtually any material; especially those materials which can be fabricated in thin sheet form. Papers are being made from many of the plastics as well as from the conventional wood fibers.

Wood-fiber paper honeycombs are used for many purposes, many of which are semi-structural or even non-structural. Semi-structural uses include lateral stiffening for doors, curtain walls, and office partitions. Structural-grade honeycombs are used as cores in load-bearing walls and in floors and roofs. Special properties are required for the cores used in the structural sandwich panels intended for Military shelters.

The existing specification for structural grade paper honeycombs, MIL-H-21040A, was originally written around the physical properties of one brand of honeycomb made from kraft paper. This brand was, presumably, the only one available at that time which met certain performance requirements. Subsequently, other manufacturers have developed a variety of honeycombs which are said to be suitable for use in Military hard-shelters. The existing MIL-H-21040A is said to unnecessarily restrict the use of some of these newer honeycombs.

This specification classifies the kraft-paper honeycomb according to types and classes. It specifies unit weight, strength, modulus and water migration for each type and class. In order to optimize performance, users have been procuring hybrid honeycombs with some properties of one type and class and with other properties of another type and class.

This investigation dealt only with those structural-grade honeycombs which were made from wood-fiber papers (kraft) and which were especially treated to increase wet strength and to decrease water migration rates.

1.3 Scope

The honeycombs included in this investigation were procured from four different manufacturers and were to be the low-water migration type (MIL-H-21040A Type II). The following physical properties were evaluated:

1) Strength (Compressive, shear, and tensile)
2) Water migration (from cell to cell)
3) Shear modulus
4) Effect of moisture on strength and modulus
5) Effect of thickness on strength and modulus.

The methods used in evaluating these properties are described in MIL-STD 401B, "Sandwich Constructions and Core Materials; General Test Methods".

This standard describes two methods for determining the shear strength and modulus of the core material. Both of these methods were used in this study.

2. Preparation of Specimens

2.1 Honeycomb Samples

Samples of expanded fully-cured honeycomb were ordered from four manufacturers. All were to be MIL-H-21404 Type II (maximum water migration of 1 cell in 24 hours). Three thicknesses (1, 2 and 3 in) and two densities[1/] (2 and 4 pcf) for each thickness were ordered.

Table 1 is a listing of the samples received. The honeycomb from the four manufacturers are identified in this report at Brand A, B, C and D. The unit weights reported were determined after conditioning for at least 2 weeks at 73°F, 50% rh.

Brand B honeycomb was received as 46 in x 72 in blankets, but these blankets were made up from 4 individual pieces of honeycomb spliced together longitudinally with a rigid foamed polymer. It should be noted that the unit weights of the Brand B blankets are considerably greater than that specified (nominal) because of the splicing.

[1/] In this report the commercial term "density" is used to denote the "unit weight" of the expanded honeycomb.

All samples were received in fair or better condition and had been well packaged. Typical defects in the honeycomb as received were crushed and broken blanket corners or edges.

The 2 pcf Brand C and the Brand D honeycombs had a significant number of small half-moon shaped pieces broken from the cell edges.

Brand A, B and C were typical honeycombs with hexagonal shaped cells. Brand D was the single corrugation type with the cells formed by sinewave corrugations of paper ribbon. Figure 1 illustrates the configuration of the two types of honeycomb.

The surfaces of the Brand D honeycomb blankets contained many high and low spots in addition to a slight undulation in the surface of some blankets. These manufacturing defects appeared to be a result of the sawing and of the subsequent resin dipping. The resin is attracted in globules to fine wood fiber threads sticking up along the undulating sawed surface, causing high spots.

These manufacturing irregularities in the Brand D honeycomb surfaces resulted in variation in blanket thickness of 1/16 in, or more, in some areas.

2.2 Preparation of Specimens

Most of the test procedures used in evaluating the honeycombs required that facings or plates be bonded to the core. To simplify the preparation of these specimens, 45 in x 45 in sandwich panels were first fabricated using 0.062 in high pressure laminate (Formica) as facings cold bonded to the sample honeycombs. Specimens of the required sizes were then cut from the panel material using a band saw with a fine tooth blade. See Table 2 for specimen sizes. The facings had an average tensile strength of 11,500 psi and an average tensile modulus of 1.52×10^6 psi.[2/] High pressure laminate was used for the facings because of the simple cleaning procedure required for adhesive bonding.

The adhesive used for all bonding was a 1:1 mixture by volume of an epoxy resin and a polyamide curing agent (Shell 828 Epon and Epon curing agent V25). In addition, a small amount of a finely divided silica (Cab-O-Sil) was added to make the mixture thixotropic. At room temperature (75°F) this adhesive has an initial gel time of about 30 min. Handling strength is attained in a few hours at room temperature, but "final cure" is not attained for about one week.

2/ The tensile strength and modulus for the high-pressure laminate was determined from long-span flexural tests on specimens made from the same materials.

The adhesive was spread on the facings with a piece of dull band saw blade to a thickness of 0.03 in. The panels were then laminated in a vacuum press table held at 10 psi for a minimum of 12 hours.

The water-migration specimens were 5 in x 5 in pieces of honeycomb bonded with the epoxy adhesive to 1/8 in thick, clear acrylic plates. After bonding a hole was drilled through one acrylic plate into a centrally located cell of the honeycomb. A short piece of 5/16" rigid acrylic tubing was inserted into this hole and bonded to the plate.

Honeycomb for the water-migration specimens was selected so that there were no defects in the edges of the cells which would not be sealed by the bonding adhesive when spread about 0.06 in thick. Considerable difficulty was encountered in getting good specimens for the Brand D honeycomb because of the surface irregularities described in Section 2.1.

All the strength specimens, except for a few compressive test specimens, were cut from the laminated sandwich panels. These exceptions were conditioned and tested without facings. They were prepared for test by "capping" them with an epoxy resin. The capping resin formed fillets about 1/8 in high on the edges of the paper. A hole was made through the hardened

resin into each cell to provide for circulation of moisture within each cell.

Brand B honeycomb specimens were cut so that the core splices would not be in a position to influence the test results. Most of these specimens contained no splices, but the 3 in thick shear specimens for the "L" direction had splices near one of the ends.

2.3 Conditioning of Specimens

All honeycomb samples were conditioned for at least 2 weeks in the laboratory air controlled at 75 ± 3°F and 50 ± 5% rh. The samples were laminated into the sandwich panels at the same ambient conditions. After lamination, test specimens of the required sizes were cut.

The specimens to be tested "dry" were stored and tested at 75°F and 50% rh. Specimens to be tested "wet" were conditioned for 7 days in a chamber held at 80 ± 5°F and 97 ± 2% rh. A few compressive test specimens, which had no facings, were soaked in room temperature (75°F) water for 24 hours for a comparison with the other "wet" specimens. All wet specimens were tested immediately following the conditioning.

3. Test Procedures

All test procedures were essentially as described in MIL-STD 401B. For the convenience of the reader the basic features of each procedure are described below and are indicated in Figure 2. In all tests the rate of loading was chosen so that failure would occur in 3 to 6 minutes.

3.1 Compressive Strength Test

This procedure is described in Section 5.1.4 of 401B. The flatwise compressive strengths were determined by applying, at a constant rate, an axial compression load through a spherical head to heavy, (1 in thick) flat plates placed on the specimens. Deformations were not measured during these tests.

3.2 Tensile Strength Test

This procedure is described in Section 5.2.3 of 401B. The flatwise tensile strengths were determined by applying at a constant rate an axial tensile load to heavy steel plates (1 1/4 in thick) bonded to the facings of the specimens. The load was applied to the plates through universal joints attached to spherically seated pull rods.

For many of the "wet" tests initial failure was in the bond between the honeycomb and the facing, or plate, instead

of in the honeycomb. For the purpose of this study it was assumed that, unless 75% of the honeycomb failed, the bond was the "weakest link" and the test result was thrown out. Deformations were not measured during these tests.

3.3 Water Migration Test

This procedure is described in Section 5.1.7 of 401B. The amount of water migrating in 24 hours from one centrally located cell in a 5 x 5 in specimen is determined by this test. Initially, the center cell is filled with water and the amount of water required to fill the cell is measured. Distilled water under a constant head of 3 ft is connected to the tube leading from the center cell in the specimen and the amount of water required to maintain the head is measured.

Close control and observations were required to insure that the adhesive bonding had sealed all cell edges to the clear acrylic plate. The water leakage patterns could be easily observed. A specimen was removed from test when it was observed to be leaking through the plate bond or when the amount of water required to initially fill the center cell was so abnormal as to indicate leakage.

3.4 Plate Shear Test

This procedure is described in Section 5.1.5 of 401B and is denoted as the core shear test. With this procedure the honeycomb specimens are bonded between two thick steel plates which are displaced relative to each other during test. This displacement places the honeycomb specimen in shear. For this study the plates were displaced by applying a compressive load to the ends of the plates through a spherical loading head. Relative displacement of the pair of plates was measured with a 0.0001 in dial gage.

For this study the shear modulus was determined directly from the load-displacement data with no allowance being made for the shear resistance offered by the facings.

3.5 Flexural Shear Test

This procedure is described in Section 5.2.4 of 401B using quarter point loading[3/]. The specimen length (see Table 2) was chosen so that shear failure would be produced in the honeycomb. In order to prevent local crushing of the honeycomb at the load or reaction points thin steel plates (1/8 in x 1 1/2 in wide) were placed at these points to distribute the loads.

[3/] In the September 1967 Edition of the MIL-STD-401B there are a few typographical errors in this section. ASTM C-393 should be consulted for the corrections.

Deflections of the specimens at midspan were measured by a 0.001 in dial gage.

4. Test Results

4.1 General Comments

Test results for this study are presented in a series of tables and figures. The data presented in the tables are average values for at least 5 specimens. Blanks in the tables indicate that either insufficient or no data were developed. In some cases, specimens were not available due to lack of honeycomb while in other cases the raw test data was suspect for one reason or another.

In testing some "wet" specimens the adhesive bond was insufficient to properly evaluate the honeycomb. This condition was especially true for the tensile tests. For the tensile tests, unless failure occurred in the honeycomb over at least 75% of the specimen area the test was not included.

The data plotted in the figures are, unless stated otherwise, the average values presented in the tables. The figures are used to show the relationships either between two mechanical properties or between some mechanical property and the density or thickness of the honeycomb.

The densities indicated in the figures are those for the honeycombs conditioned at 73°F and 50% rh for at least 2 weeks.

The locations of the lines drawn through the plotted points were computed using least-squares. The computed formulae for these lines are included on each figure.

As has been pointed out previously by others[4/] the relationship between the wet and dry strengths and moduli depends on the moisture content of the paper honeycomb. The moisture content depends on the size and type of specimen, the method and time of conditioning and on the method of impregnating the paper. For the purposes of this study it was thought that conditioning at 100% rh for 7 days would better simulate expected service conditions than would soaking for several days in water.

4.2 Compressive Test Results

The compressive test results are presented in Table 3 and Figure 3. It is obvious that the compressive strength of Brand D honeycomb is significantly less than the other

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[4/] See Jenkinson, P.M., Effect of core thickness and Moisture Content on Mechanical Properties of Two Resin-Treated Paper Honeycomb Cores, U.S. Forest Service Research Paper FPL 35, Forest Products Laboratory, Madison, Wisc., September 1965.

brands. Although Brand D data are plotted in Figure 1 they were not included when computing the formulae for the lines.

It should be noted that the line for the "wet" strength in Figure 1 is just 50% of that for the "dry".

Any consistant effect of the core thickness on the compressive strength could not be determined.

4.3 Tensile Test Results

The tensile test results are presented in Table 4 and Figure 4. Very little can be learned from this data other than that the tensile strength is a function of the density of the core. The lack of sufficient data for the "wet" tests does point out the need for extreme care in the bonding operation and in the choice of the adhesive.

In general the bond of the core to the high-pressure laminate facings was better than the bond to the heavy steel loading plates.

Some failures in the tensile tests could probably be attributed to eccentric application of load across the face of the specimen. Whether this eccentricity in loading is a result of heterogeneous honeycomb or of improper alignment during testing is not clear.

As in the case for the compressive strength tests, no effect of specimen thickness could be determined.

4.4 Water Migration Test Results

The results for the water migration tests are presented in Table 5. It should be recalled that the samples ordered were to be 21040A Type II honeycomb. The maximum water migration allowed for Type II is 1 cell in 24 hour. The test results show that all of the 2 and 2.5 pcf density honeycomb met this requirement. The results also show that none of the 4 pcf density honeycomb met the requirement.

Observations made during the test indicate that much of the water migration took place along the paper ribbons and through the nodes. This was especially evident for the 4 pcf density Brand A core.

It is interesting to note that when the test continued longer than 24 hour the migration rate decreased. The average migration during the second 24-hr period was only 36% of that during the first period. Although the tests were not continued for longer than 48 hours it is probable that the rate of migration would continue to decrease.

One byproduct of this test was an indirect method of estimating cell size. The volume of water required to fill a cell is measured during the test and knowing the height, the area of the cell can be computed. If the cell shapes are reasonably uniform a fair estimate of the cell size can be made.

Assuming that the cells were hexagonal shaped the average cell size (diameter of the enclosed circle) for Brand A, B and C was 0.471 in, 0.456 in and 0.508 in respectively. Brand D cell size was computed assuming that the shape of the cell was an equilateral triangle. Brand D cell size (height of triangle) was computed to be 0.28 in.

The specimen thickness does not appear to be a variable in these tests.

4.5 Shear Test Results

The test results for the shear tests are presented in Tables 6 through 11 and in Figures 5 through 16. Tables 6 through 9 include the data from the plate shear tests while the data for the flexural shear tests are given in Tables 10 and 11. Figures 5, 6, 12, and 13 were designed to show the effects of honeycomb density and thickness on strengths

and/or moduli. Figures 7 through 16 indicate the effects of moisture, direction of core ribbon and method of test on the data.

The data shown in Figures 6 and 13 are the average of the ratios for each set of data taken from the applicable tables. These two figures indicate clearly that the shear values determined by either the flexural or the plate test will vary with the honeycomb thickness.

The figures comparing "wet" values with "dry" values (Figures 7 and 14) clearly show a high variability in this relationship. Much of this variability is probably due to the variability in the "wettness" between the different sizes and brands of the honeycomb specimens.

5. Discussion of Results

5.1 General Considerations

One of the most favorable properties of paper honeycomb is its ability to absorb shock without fracture. It usually happens that an increase in the elastic modulus of paper results in an increase in the brittleness. Specifications have been written in such a way that a high shear modulus appears to have an advantage over a lower value. This has

resulted in the designer looking for cores with a higher shear modulus and he subsequently receives a more brittle paper.

This condition is aggravated by the water migration requirement for the Type II honeycomb. In order to attain low migration rates the manufacturer usually impregnates (or coats) his honeycomb with an abnormally large percentage of resin. The phenolic resin used imparts a higher modulus and a greater brittleness to the paper. As reported in the literature a resin content above about 15% does not appear to increase the wet to dry strength ratio, although it probably does increase the dry strength. Thus, at the present time the manufacturer has at least three reasons for increasing the resin content of his product and none, except cost, for decreasing the brittleness.

In general the strength of the honeycomb is of more importance in military shelters than the elastic moduli. On the average, for service loading conditions the compressive strength is probably of greater importance than either the tensile or shear strength, and with the tensile strength being of least importance. However, in a typical structure there are specific examples of loading conditions where any one of the three strengths may be of primary importance.

In the design of sandwich panels the dry values for the strength and modulus of the core are usually used. Experience has shown that significant quantities of moisture do enter a considerable number of panels. It seems reasonable then to assume in design that at some time in their life all panels will contain sufficient moisture to wet the core.

Low water-migration honeycomb cores theoretically should prevent the migration of liquid water to areas some distance from a water leak. Practically speaking this should not be assumed as there are other paths by which water can migrate through the core of a panel. Defects in the cell edges can prevent complete sealing of the core to the facings. Lack of uniform thickness in the core can also cause incomplete sealing. Another path for water migration is core splices. Since honeycomb is now being made only in widths up to 48 in, most panels used in the military hard shelters will have splices in the panel cores.

The density of the core is chosen after considering the requirements for strength and rigidity. Normally the lightest available core which meets the other considerations is chosen. Actually there are only about two densities of water migration honeycomb available because of the way the specifications (2104A) are written. This means that the designer has two choices, 2 or 4 pcf densities.

The designer would save about 30 lb of weight in an 8 ft x 8 ft panel 2 in thick if he chose the 2 pcf over the 4 pcf core. Savings in cost could be as much as $35 per panel. Whether these apparent savings are justified when the properties of the 2 pcf paper are marginal is a matter of judgment, but in many cases they are not. This would be especially true when only one panel of several in a shelter requires 2 pcf core.

5.2 Effect of Density on Properties

The density of the honeycomb as shown in Figures 3, 4 and 5 has a significant effect on the measured strengths. The shear and compressive strengths of the 4 pcf core was about three times that of the 2 pcf. The tensile strength at 4 pcf was about two times that at 2 pcf.

The Brand D shear and compressive strengths were significantly less than the other brands. It should be remembered that Brand D was received only as 4 pcf density and was made with a different configuration (sine wave or triangular shaped cell) than the others (hexagonal). An anomaly is apparent in the Brand D shear strength data presented in Figure 5 and the shear modulus data of Figure 12. First, in Figure 5 the "wet" strengths for Brand D are shown as being only slightly less than the dry. Second, in Figure 12 Brand D shear modulus values are above the average. These

comparisons indicate that the Brand D honeycomb must have been treated so that it either "wets" less than the others or its wet to dry strength ratio is better; and second that the modulus to strength ratio is greater for Brand D than for the others.

The water migration rate is apparently affected by the density of the paper. The heavier the paper the greater the migration. From observations made during the water migration tests it is apparent that much of the movement of the water is along the paper ribbon and that the heavier the paper the greater the movement.

The apparent decrease in the rate of water migration with time is probably a result of the test method, whereby the pressure on the water decreases with the distance from the initial cell.

5.3 Effect of Core Thickness on Properties

It has been shown by Jenkinson (See footnote 4) and others that the thickness of a specimen has considerable effect on the measured strength and modulus. Previous data was for thicknesses from 1/4 in to 2 in. The data from this study was developed for thicknesses from 1 in to 3 in which are more representative of the cores that might be used in the shelter programs.

Clearly, the thickness of the specimen affects the shear values determined for the same honeycomb. The data in Figures 6 and 13 show that the greater the thickness the lower the shear strength and modulus. Figure 6 indicates that the average shear strength for a 2 in thick specimen would be only 86% of that for a 1 in thick specimen. The data of Figure 13 indicates an ever greater reduction for the shear modulus.

When considering the effect of core thickness on the compressive and tensile strengths the data indicates that if there is any effect it is masked by the variability in the test results.

5.4 Effect of Ribbon Direction on Properties

The data presented in Figures 8, 9 and 10 show that there is a reliable relationship between the shear strength in the "L" direction with that in the "W" direction. This relationship for Brand D is different than for the other brands of honeycomb. Similar conclusions can be drawn from the shear moduli data presented in Figures 15 and 16.

This relationship will obviously vary with cell configuration and expansion ratio. The data indicate, that for practical purposes, the hexagonal shaped honeycombs of this study are quite similar in expansion ratio.

5.5 Effect of Moisture on Properties

The data in Figure 3 indicate that the compressive strengths for all honeycombs except Brand D are reduced 50% from the dry values when conditioned for 7 days at 100% rh. The data for Brand D indicates a significantly smaller effect from the high-humidity conditioning.

The data for the shear strengths and moduli, presented in Figures 7 and 14, show a similar effect from the high humidity conditioning.

Insufficient data were developed to indicate the effect of moisture on the tensile strength, but it is probably similar to the effect on the compressive and shear strengths.

5.6 Effect of Test Method on Shear Properties

For determining the shear properties of honeycomb, the shear flexural method is preferred over the plate methods because of its simplicity. The data of Figure 11 shows that the flexural method would develop slightly lower average shear strength values (7%) than the plate method.

Shear modulus values computed from the flexural tests were considerably less than the values from the plate shear tests. A comparison of these values is not presented in this

report because the reason for the difference has not been determined.

A shear modulus is determined directly from the plate test data, but indirectly from the flexural data. A number of approximations must be used to compute modulus values from the flexural data. Thus, at best the flexural values for the shear modulus should be considered approximate. Preliminary analysis of the data from this study indicate that the flexural shear moduli are considerably less and not even an approximation of those found by the plate shear method.

At this time, the reason for the difference between the two modulus values is not apparent. Additional testing and a more rigorous analysis of test data are required to explain this inconsistancy.

6. Summary of Conclusions

1) The Brand D honeycomb was significantly different from the other brands in strength and modulus.

2) The tensile, compressive and shear strengths and the shear modulus are roughly proportional to the density of the paper honeycomb.

3) The water migration rate was significantly greater for the 4 pcf honeycomb than for the 2 pcf.

4) The thickness of the test specimen significantly affects the shear values determined by either the plate or flexural shear test methods.

5) The thickness of the test specimen does not significantly affect the tensile and compressive test results.

6) There is a consistant relationship between the shear strength and modulus in the "L" direction with that in the "W" direction.

7) The strengths and shear modulus for honeycombs conditioned at 100% rh for 7 days are only 50-60% of those for dry honeycombs.

8) The shear strengths of honeycombs determined by the flexural shear method averaged about 93% of those determined by the plate shear method.

9) In design it should be assumed that the cores in sandwich panels will, sometime in their life, become wet.

7. Acknowledgements

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Table 1. Paper Honeycomb Samples Received

Brand	Nominal Density of Core	Number of Blankets Received	Average Blanket Size			Average Unit Weight of Blankets	Unit Weight[1] of Core Sample	Cost of Core
			Thickness	Width	Length			
	pcf		in	in	in	pcf	pcf	$/bd-ft [3]
A	2.0	1	1	43	73	2.02		
A	2.0	1	2	43	73	2.14		
A	2.0	1	3	43	73	2.16		
A	2.5	1	1	43	73	2.49		
A	2.5	1	2	43	73	2.59		
A	4.0	1	2-3/8	43	73	4.06		
B[2]	2.0	1	1	46	72	4.44	2.22	0.56
B[2]	2.0	2	2	46	71-5/8	3.85	2.07	.32
B[2]	2.0	3	3	46	72	3.78	2.01	.26
B[2]	4.0	1	1	46	72	6.57	3.85	.80
B[2]	4.0	2	2	46	72	5.61	3.89	.52
B[2]	4.0	3	3	46	72	5.66	3.74	.46
C	2.0	1	1	44-5/8	97-1/4	2.19		.36
C	2.0	2	2	45	95	2.23		.33
C	2.0	3	3	45	97-1/8	2.16		.32
C	4.0	1	1	45	96	3.90		.50
C	4.0	2	2	45	98	3.95		.47
C	4.0	3	3	45-1/8	98-3/4	3.90		.46
D	4.0	3	1	24-1/2	48-1/2	4.55		
D	4.0	6	2	23	48-1/8	4.17		
D	4.0	9	3	24-3/16	48-1/6	4.08		

1/ From an unspliced sample cut from blankets.

2/ Full-size blankets had 3 or more longitudinal slices.

3/ A board-foot (bd-ft) is 12 in x 12 in x 1 in thick.

Table 2. Test Specimen Sizes 1/

Test	1 in thick		2 in thick		2 3/8 in thick		3 in thick	
	Width in	Length in	Width in	Length in	Width in	Length in	Width in	Length in
Tension	2	2	2	2	3	3	3	3
Compression	2	2	2	2	3	3	3	3
Plate Shear	2	12	4	24	6	25.5	6	25.5
Flexural Shear	2	10	4	15	6	18	6	18
(span, in.)	-	(8)	-	(12)	-	(14)	-	(14)

1/ All water migration specimens were 5 in square.

Table 3. Average Compressive Strength, Flatwise

Brand	Condition at Test	2 - pcf Density 1/ 1" Thick	2" Thick	3" Thick	4 - pcf Density 1/ 1" Thick	2" Thick	3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	146 4/	162 4/	130	---	---	441 5/
A	Wet 3/	62 4/	48 4/	78	---	---	293 5/
B	Dry 2/	222	141	142	500	383	412
B	Wet 3/	95	55	59	181	152	150
C	Dry 2/	185	197	195	487	473	493
C	Wet 3/	100	124	98	262	242	263
D	Dry 2/	---	---	---	321	257	276
D	Wet 3/	---	---	---	145	102	156

1/ Nominal density, see Table 1 for actual density.

2/ Conditioned at 50% rh, 73°F.

3/ Conditioned for 7 days at 100% rh, 75°F.

4/ Average for 5 specimens from each of 2 densities, 2.0 and 2.5 pcf.

5/ Thickness was 2-3/8 in.

Table 4. Average Tensile Strength, Flatwise

Brand	Condition	2 - pcf Density 1/ 1" Thick	2 - pcf Density 1/ 2" Thick	2 - pcf Density 1/ 3" Thick	4 - pcf Density 1/ 1" Thick	4 - pcf Density 1/ 2" Thick	4 - pcf Density 1/ 3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	263 4/	279 4/	208	---	---	381 5/
A	Wet 3/	---	---	147	---	---	---
B	Dry 2/	269	254	247	426	419	392
B	Wet 3/	---	---	---	---	---	---
C	Dry 2/	234	174	197	370	320	329
C	Wet 3/	120	---	---	---	---	---
D	Dry 2/	---	---	---	---	---	351
D	Wet 3/	---	---	---	---	---	224

1/ Nominal density, see Table 1 for actual density.

2/ Conditioned at 50% rh, 73°F.

3/ Conditioned for 7 days at 100% rh, 75°F.

4/ Average for 5 specimens from each of 2 densities, 2.0 and 2.5 pcf.

5/ Thickness was 2-3/8 in.

Table 5. Water Migration Rate

(Number of Cells Filled in Indicated Time)

Brand	2 pcf Density 1/						4 pcf Density 1/					
	1 in Thick		2 in Thick		3 in Thick		1 in Thick		2 in Thick		3 in Thick	
	24hr	48hr	24hr	48hr	24hr	48hr	24hr	48hr	24hr	48hr	24hr	48hr
A	0.2	--	0.1	--	0.1	--	--	--	--	--	3.7 3/	--
A 2/	1.0	--	0.4	--	--	--	--	--	--	--	--	--
B	0.7	0.8	--	--	0.2	0.2	2.8	4.1	1.5	2.3	1.7	2.3
C	0.3	0.4	0.6	0.8	0.4	0.5	1.9	3.0	3.6	4.9	3.2	4.3
D	--	--	--	--	--	--	13.0	17.2	5.8	8.6	8.0	13.0

1/ Nominal density, see Table 1 for actual density.

2/ Nominal density = 2.5 pcf.

3/ Thickness = 2-3/8 in.

Table 6. Average Plate Shear Strength, "L" Direction

Brand	Condition	2-pcf Density 1/			4-pcf Density 1/		
		1" Thick	2" Thick	3" Thick	1" Thick	2" Thick	3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	69	59	57	---	---	167 5/
A	Wet 3/	52	---	---	---	---	---
A	Dry	75 4/	66 4/	---	---	---	---
A	Wet	64 4/	54 4/	---	---	---	---
B	Dry 2/	114	84	76	223	221	167
B	Wet 3/	74	45	53	109	120	138
C	Dry 2/	104	89	85	248	212	202
C	Wet 3/	57	62	63	155	143	150
D	Dry 2/	---	---	---	251	176	167
D	Wet 3/	---	---	---	127	114	117

1/ Nominal density, see table 1 for actual density.

2/ Conditioned for at least 14 days at 50% rh-73°F prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place

4/ Nominal density 2.5 pcf.

5/ Thickness 2 3/8 in.

Table 7. Average Plate Shear Strength, "W" Direction

Brand	Condition	2-pcf Density 1/ 1" Thick	2" Thick	3" Thick	4-pcf Density 1/ 1" Thick	2" Thick	3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	39	37	36	---	---	101 5/
A	Wet 3/	29	31	---	---	---	---
A	Dry	44 4/	50 4/	---	---	---	---
A	Wet	31 4/	32 4/	---	---	---	---
B	Dry 2/	61	46	44	176	155	143
B	Wet 3/	38	24	---	73	73	87
C	Dry 2/	58	54	52	139	140	129
C	Wet 3/	40	37	36	91	81	92
D	Dry 2/	---	---	---	101	75	59
D	Wet 3/	---	---	---	41	31	21

1/ Nominal density, see table 1 for actual density.

2/ Conditioned for at least 14 days at 50% rh-73°F prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place.

4/ Nominal density 2.5 pcf.

5/ Thickness 2 3/8 in.

Table 8. Average Plate Shear Modulus, "L" Direction

Brand	Condition	2-pcf Density 1/ 1" Thick	2-pcf Density 1/ 2" Thick	2-pcf Density 1/ 3" Thick	4-pcf Density 1/ 1" Thick	4-pcf Density 1/ 2" Thick	4-pcf Density 1/ 3" Thick
		10^3 psi	10^3 psi	10^3 psi	10^3 psi	10^3 psi	10^3 psi
A	Dry 2/	13.3	4.4	8.0	-----	-----	15.6 5/
A	Wet 3/	6.9	-----	-----	-----	-----	-----
A	Dry 4/	13.5 4/	8.0 4/	-----	-----	-----	-----
A	Wet 4/	9.4 4/	3.5 4/	-----	-----	-----	-----
B	Dry 2/	11.7	12.8	9.6	21.0	24.5	19.5
B	Wet 3/	5.4	2.2	2.4	7.8	4.7	3.9
C	Dry 2/	11.5	10.5	9.0	31.3	21.8	18.2
C	Wet 3/	5.0	2.7	1.9	9.3	6.4	4.6
D	Dry 2/	-----	-----	-----	27.5	23.0	19.9
D	Wet 3/	-----	-----	-----	10.3	11.5	11.5

1/ Nominal density, see table 1 for actual density.

2/ Conditioned for at least 14 days at 50% rh-73°F prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place.

4/ Density 2.5 pcf.

5/ Thickness 2 3/8 in.

Table 9. Average Plate Shear Modulus, "W" Direction

Brand	Condition	2-pcf Density 1/			4-pcf Density 1/		
		1" Thick	2" Thick	3" Thick	1" Thick	2" Thick	3" Thick
		10^3 psi	10^3 psi	10^3 psi	10^3 psi	10^3 psi	10^3 psi
A	Dry 2/	4.3	2.1	3.5	-----	-----	7.3 5/
A	Wet 3/	3.4	1.5	-----	-----	-----	-----
A	Dry 4/	4.5	5.1	-----	-----	-----	-----
A	Wet 4/	2.9	1.5	-----	-----	-----	-----
B	Dry 2/	5.6	5.2	4.2	11.6	9.8	9.0
B	Wet 3/	4.7	.7	1.7	3.5	1.9	1.8
C	Dry 2/	6.1	5.1	4.7	10.2	7.9	7.0
C	Wet 3/	3.0	1.6	1.0	4.0	1.9	1.4
D	Dry 2/	-----	-----	-----	7.1	5.9	5.6
D	Wet 3/	-----	-----	-----	2.8	2.5	2.4

1/ Nominal density, see table for actual density.

2/ Conditioned for at least 14 days at 50% rh-73°F prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place.

4/ Density = 2.5 pcf.

5/ Thickness = 2 3/8 in.

Table 10. Average Flexural Shear Strength, "L" Direction

Brand	Condition	2-pcf Density 1/ 1" Thick	2-pcf Density 1/ 2" Thick	2-pcf Density 1/ 3" Thick	4-pcf Density 1/ 1" Thick	4-pcf Density 1/ 2" Thick	4-pcf Density 1/ 3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	62.0	59.6	57.9	---	---	91.1 5/
A	Wet 3/	51.1	56.6	---	---	---	---
A 4/	Dry	78.1	64.0	---	---	---	---
A 4/	Wet	53.0	42.2	---	---	---	---
B	Dry 2/	115.0	90.2	82.3	252	249	228.0
B	Wet 3/	71.0	50.5	52.5	126	129	159.0
C	Dry 2/	110.0	87.3	83.6	257	233	211.0
C	Wet 3/	69.7	57.8	63.7	169	185	149.0
D	Dry 2/	---	---	---	271	203	185.0
D	Wet 3/	---	---	---	176	120	121.0

1/ Nominal density, see Table 1 for actual density.

2/ Conditioned for at least 14 days at 50% rh prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place.

4/ Nominal density 2.5 pcf.

5/ Thickness 2-3/8 in.

Table 11. Average Flexural Shear Strength, "W" Direction

Brand	Condition	2-pcf Density 1/ 1" Thick	2-pcf Density 1/ 2" Thick	2-pcf Density 1/ 3" Thick	4-pcf Density 1/ 1" Thick	4-pcf Density 1/ 2" Thick	4-pcf Density 1/ 3" Thick
		psi	psi	psi	psi	psi	psi
A	Dry 2/	38.9	37.2	31.8	---	----	----
A	Wet 3/	28.7	30/5	---	---	----	----
A 4/	Dry	51.0	51.3	---	---	----	----
A 4/	Wet	38.3	30.6	---	---	----	----
B	Dry 2/	70.6	57.1	48.1	186	159.0	146.0
B	Wet 3/	48.7	28.5	24.4	96	67.0	97.9
C	Dry 2/	68.7	55.4	52.0	140	138.0	121.0
C	Wet 3/	52.7	41.1	35.6	105	88.5	93.0
D	Dry 2/	---	---	---	110	66.4	77.5
D	Wet 3/	---	---	---	58	38.2	43.8

1/ Nominal density, see Table 1 for actual density.

2/ Conditioned for at least 14 days at 50% rh-73°F prior to test.

3/ Conditioned for 7 days at 100% rh prior to test with skins in place.

List of Figures

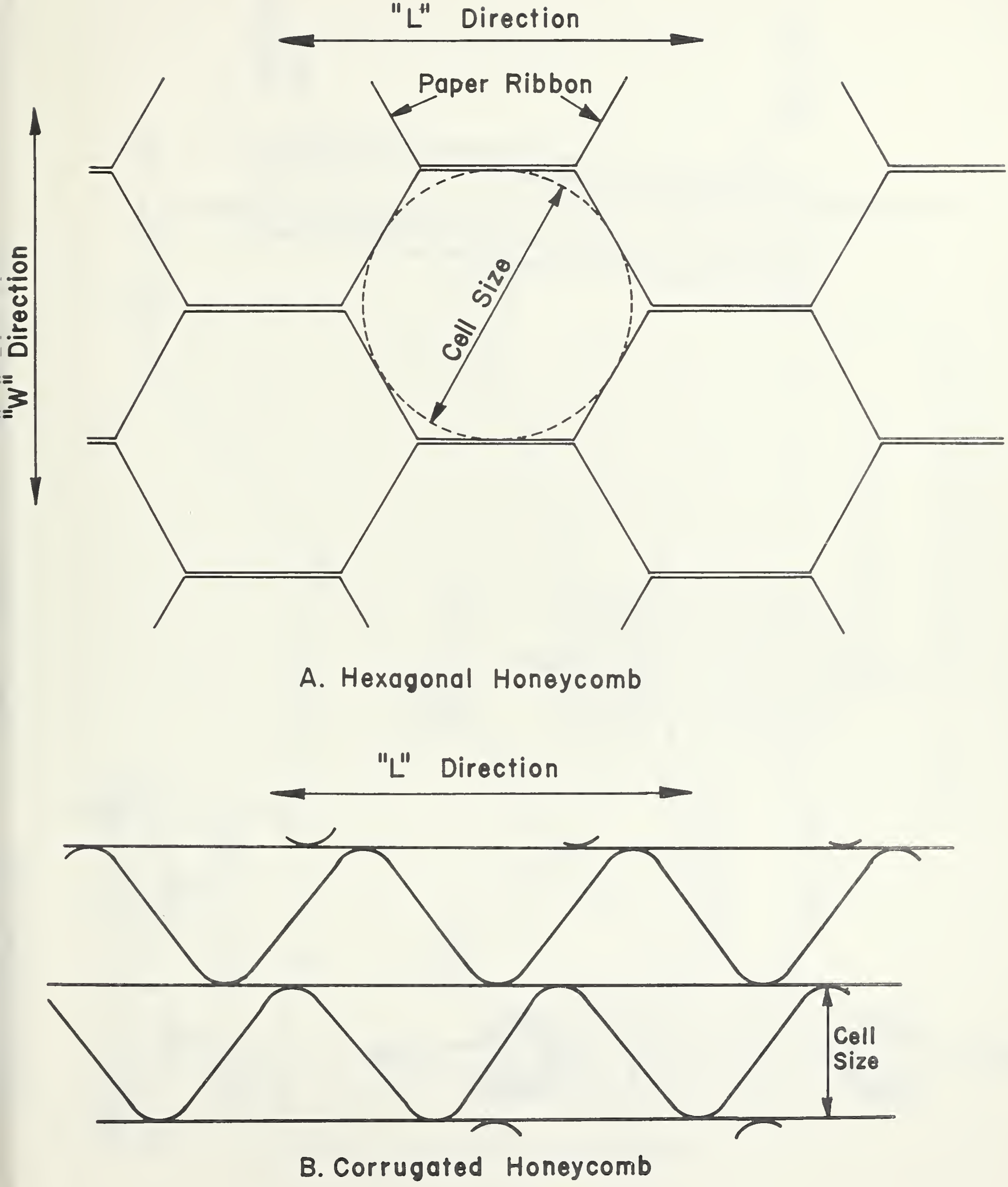

Figure 1. Honeycomb configurations.

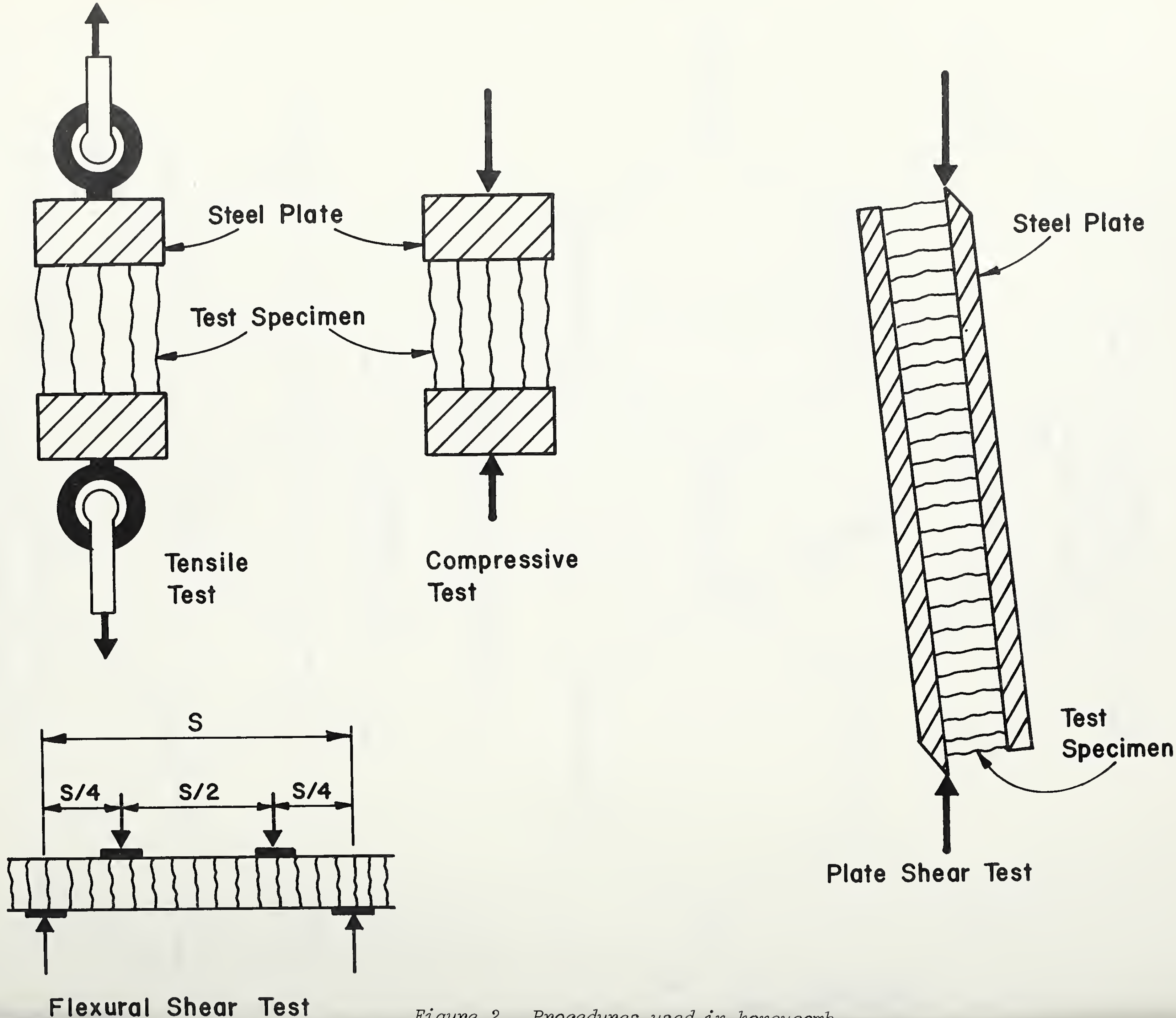

Figure 2. Procedures used in honeycomb

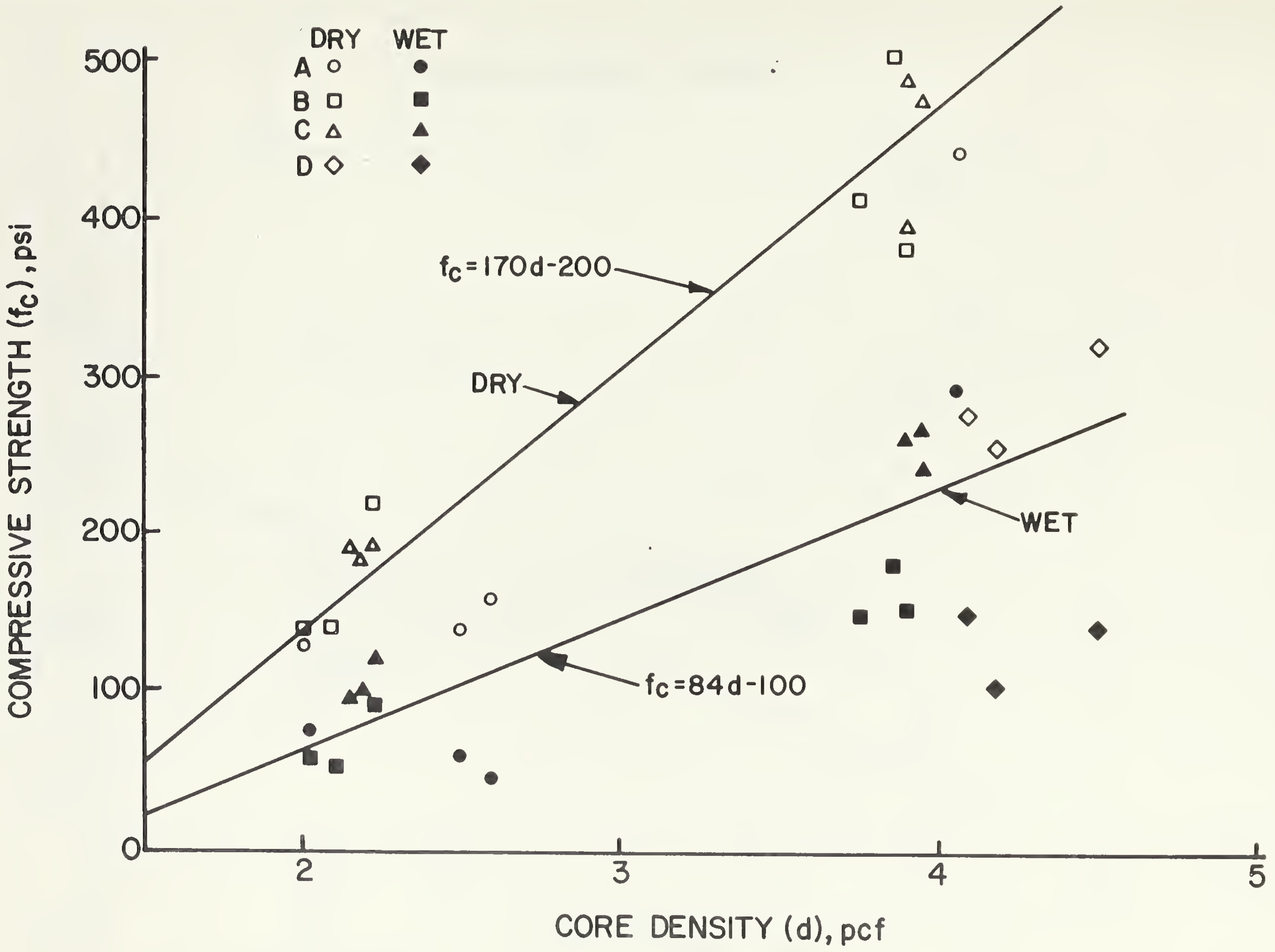

Figure 3. Compressive strength vs density for all honeycombs except D.

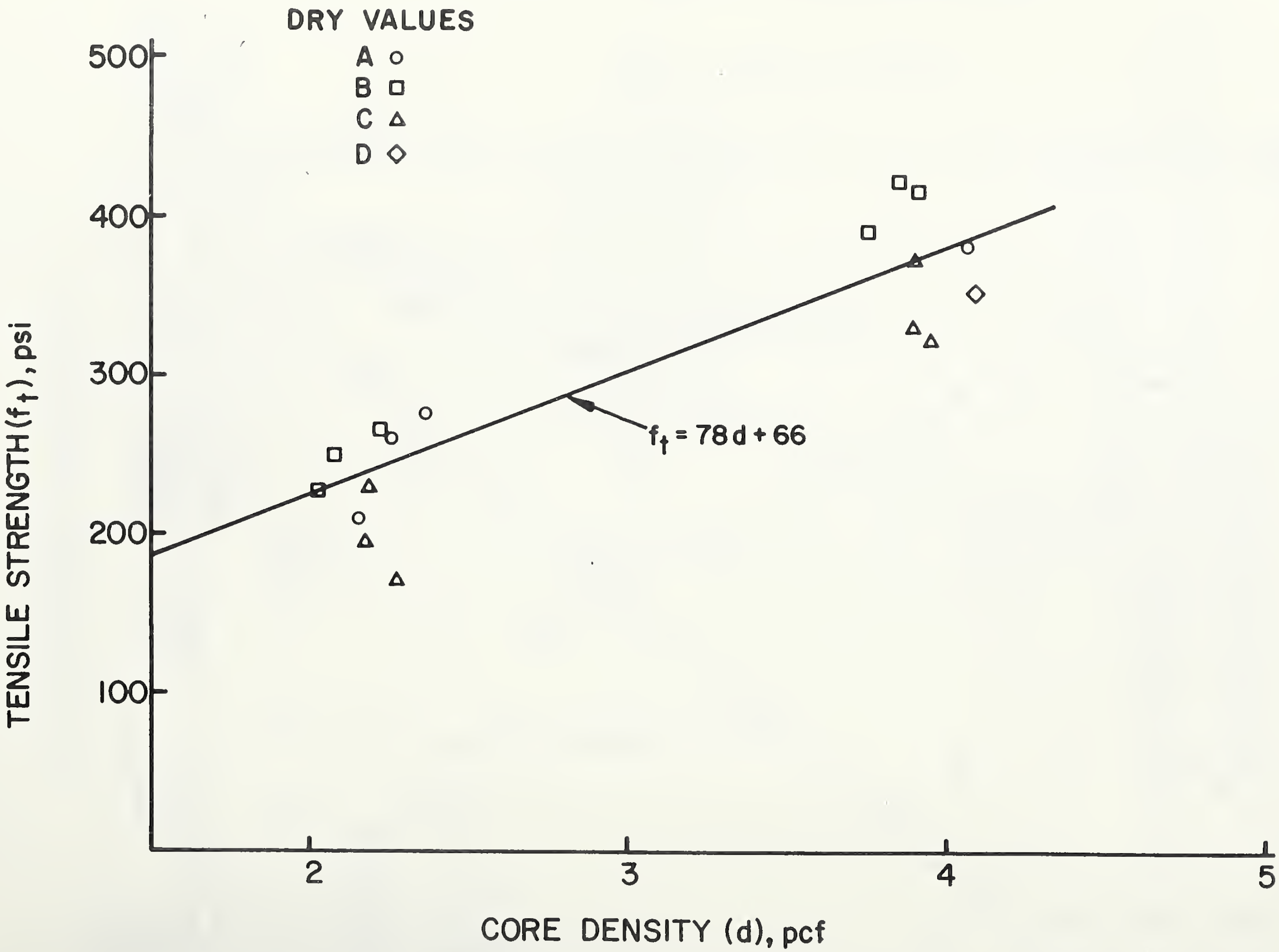

Figure 4. Tensile strength vs density for all honeycombs.

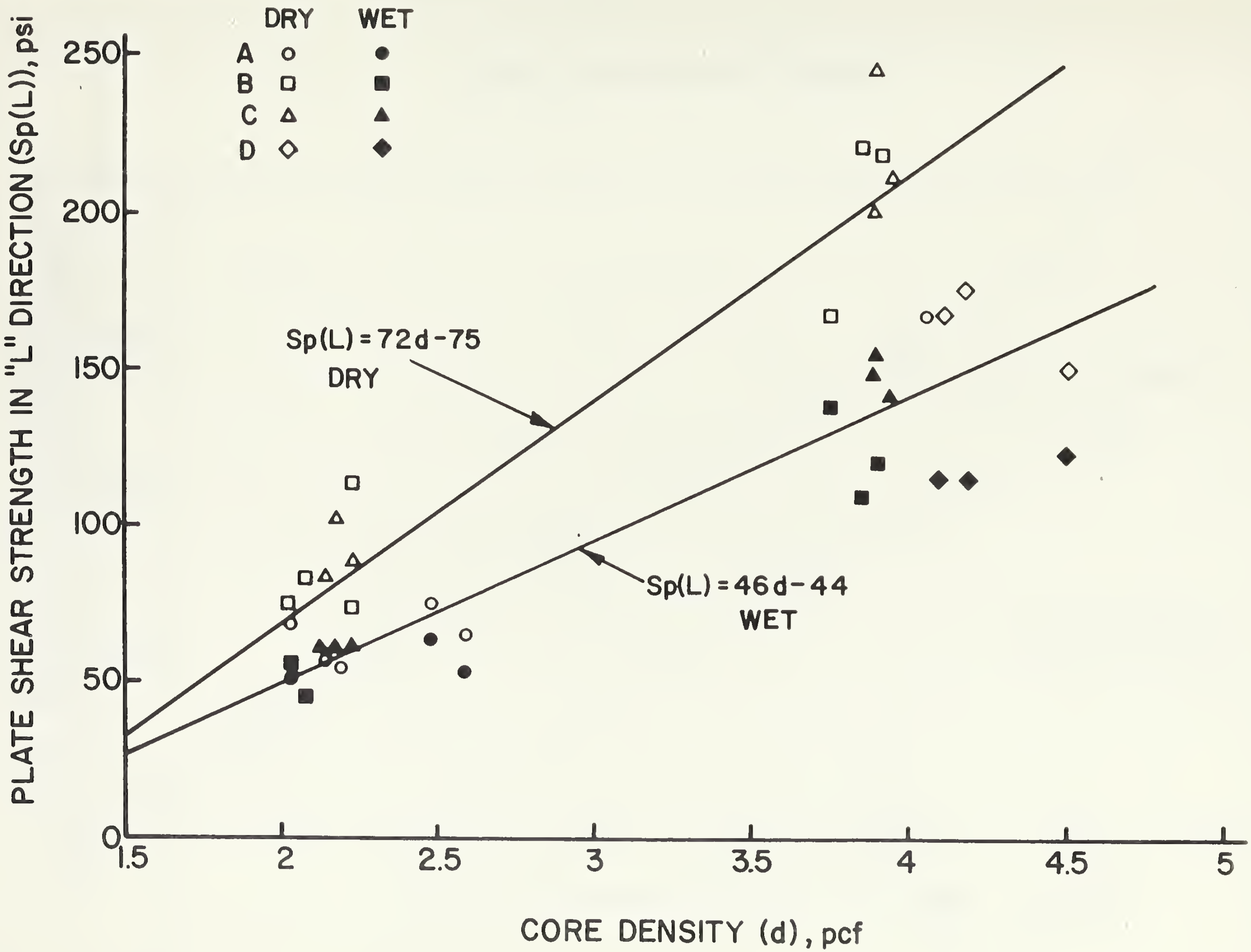

Figure 5. Plate shear strength vs density for all honeycombs.

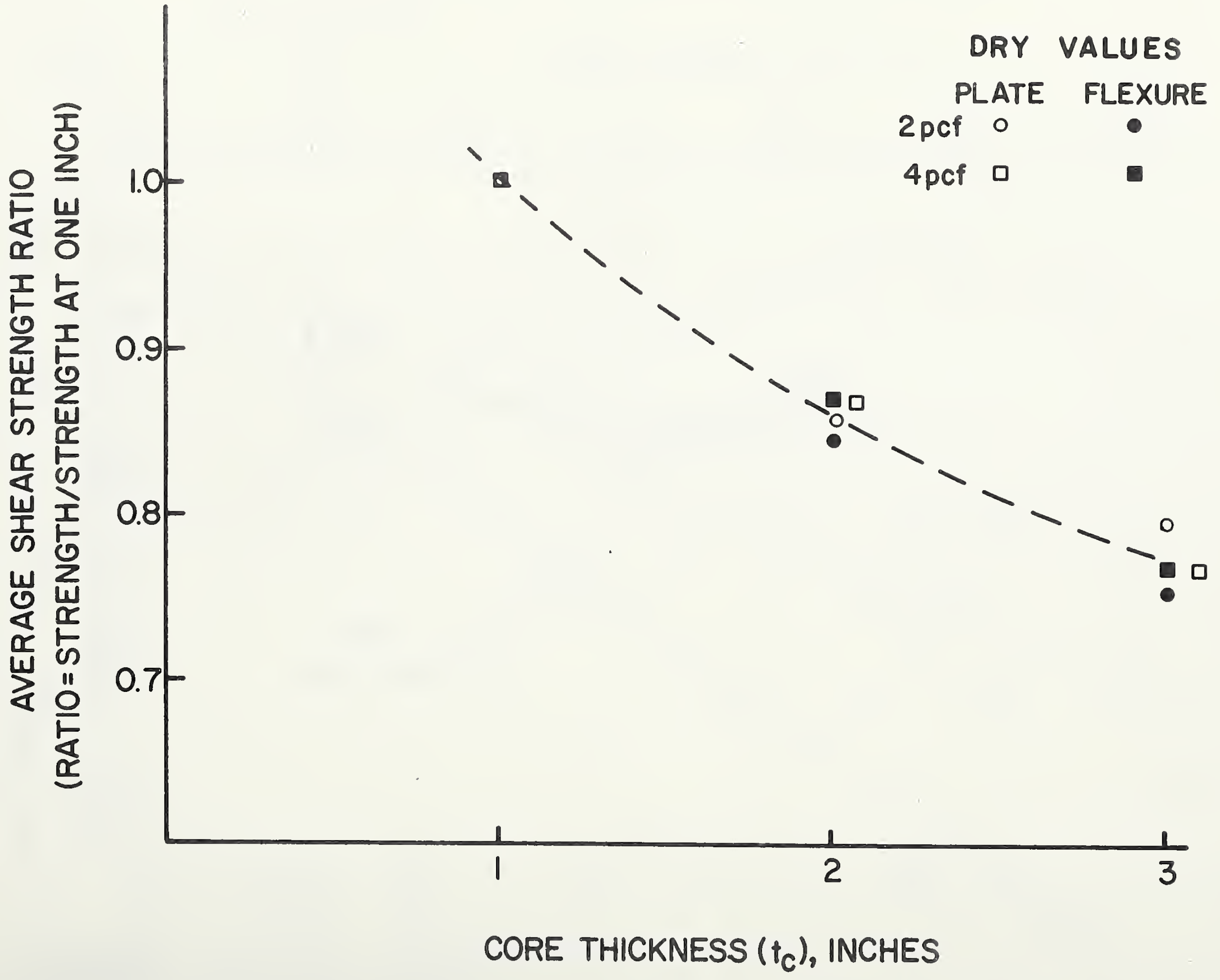

Figure 6. Effect of core thickness on plate shear strength for all honeycombs.

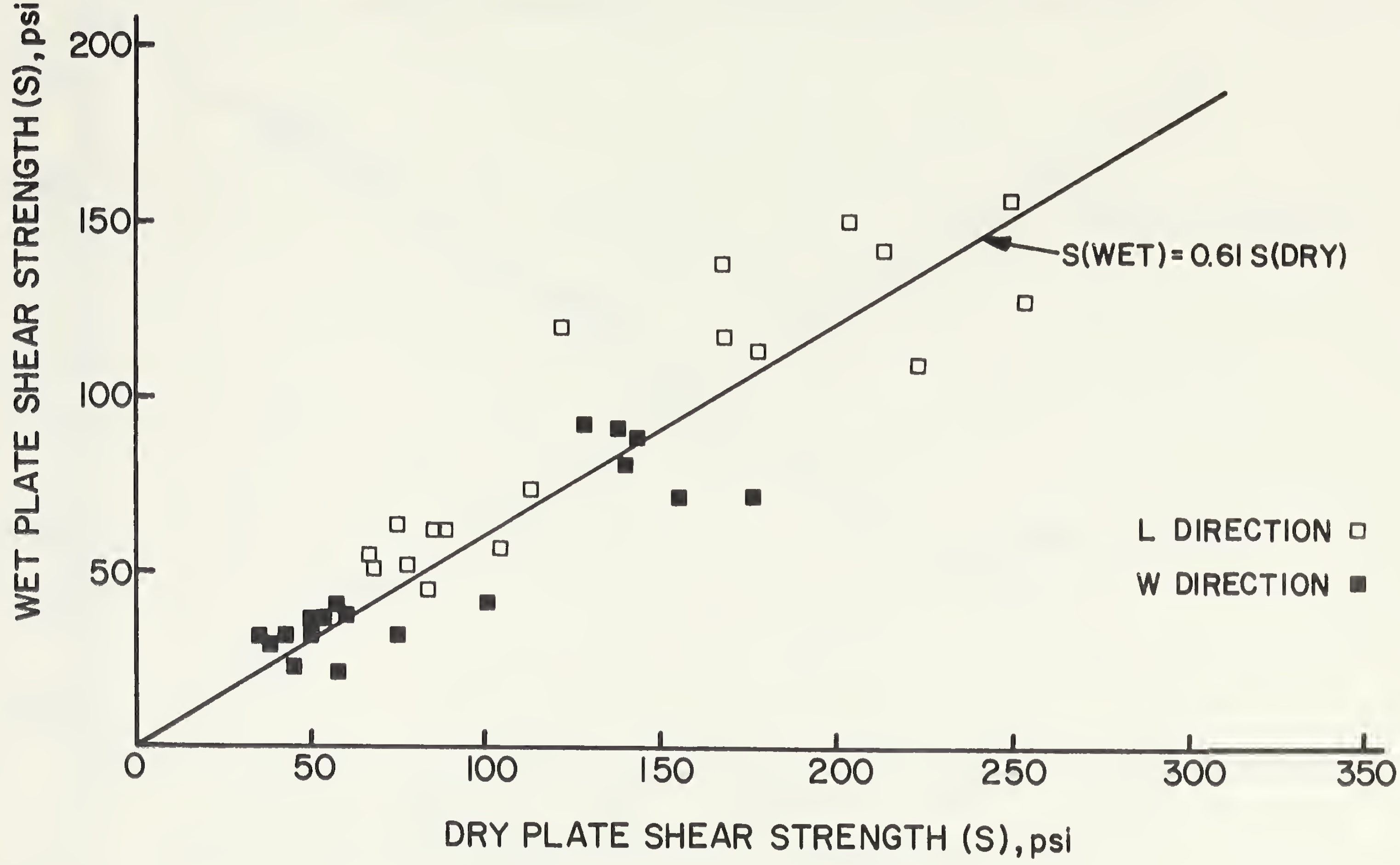

Figure 7. Wet plate shear strength vs dry plate shear strength for all honeycombs.

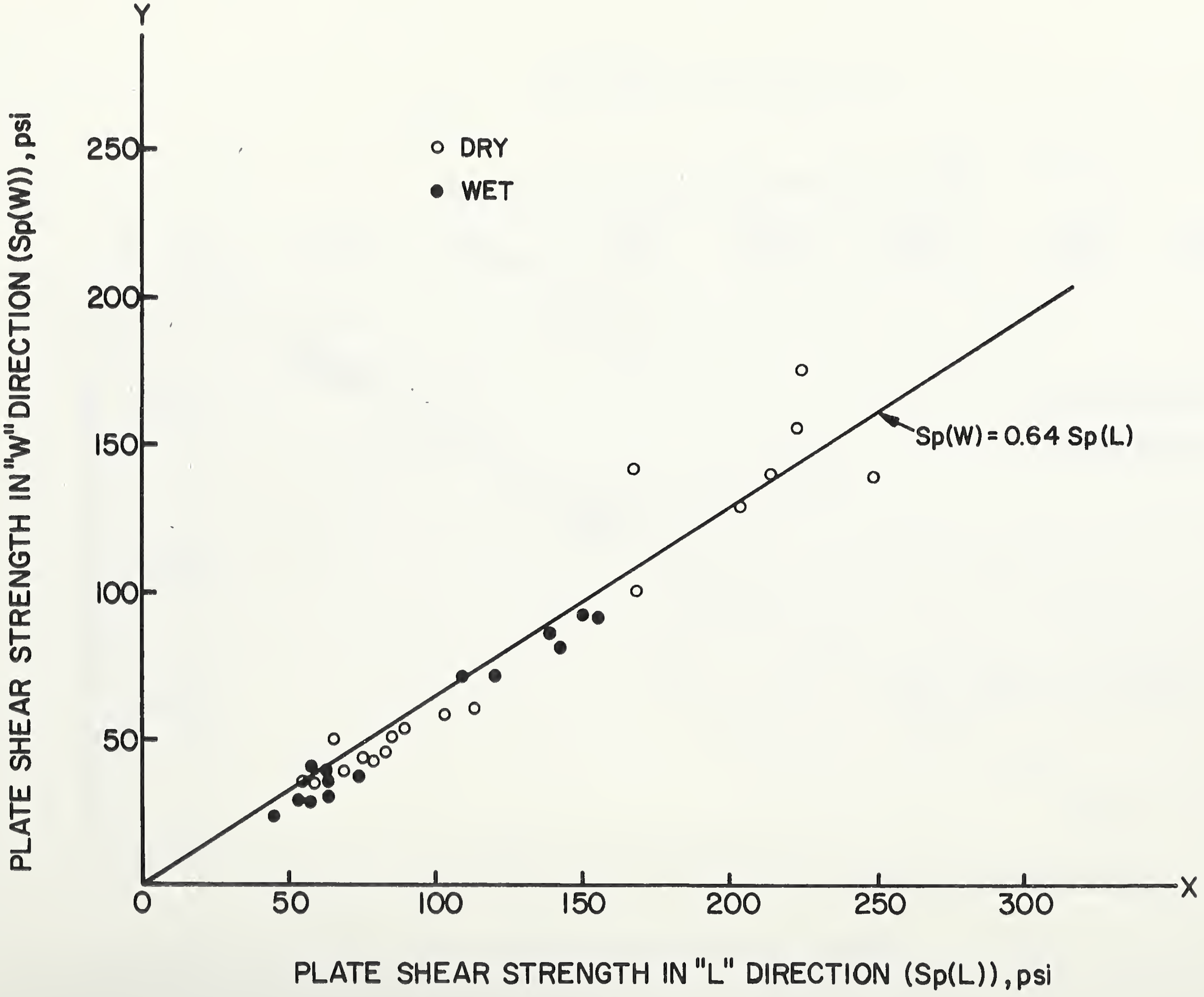

Figure 8. *Plate shear strength for all honeycombs except Brand D - "W" direction vs "L" direction.*

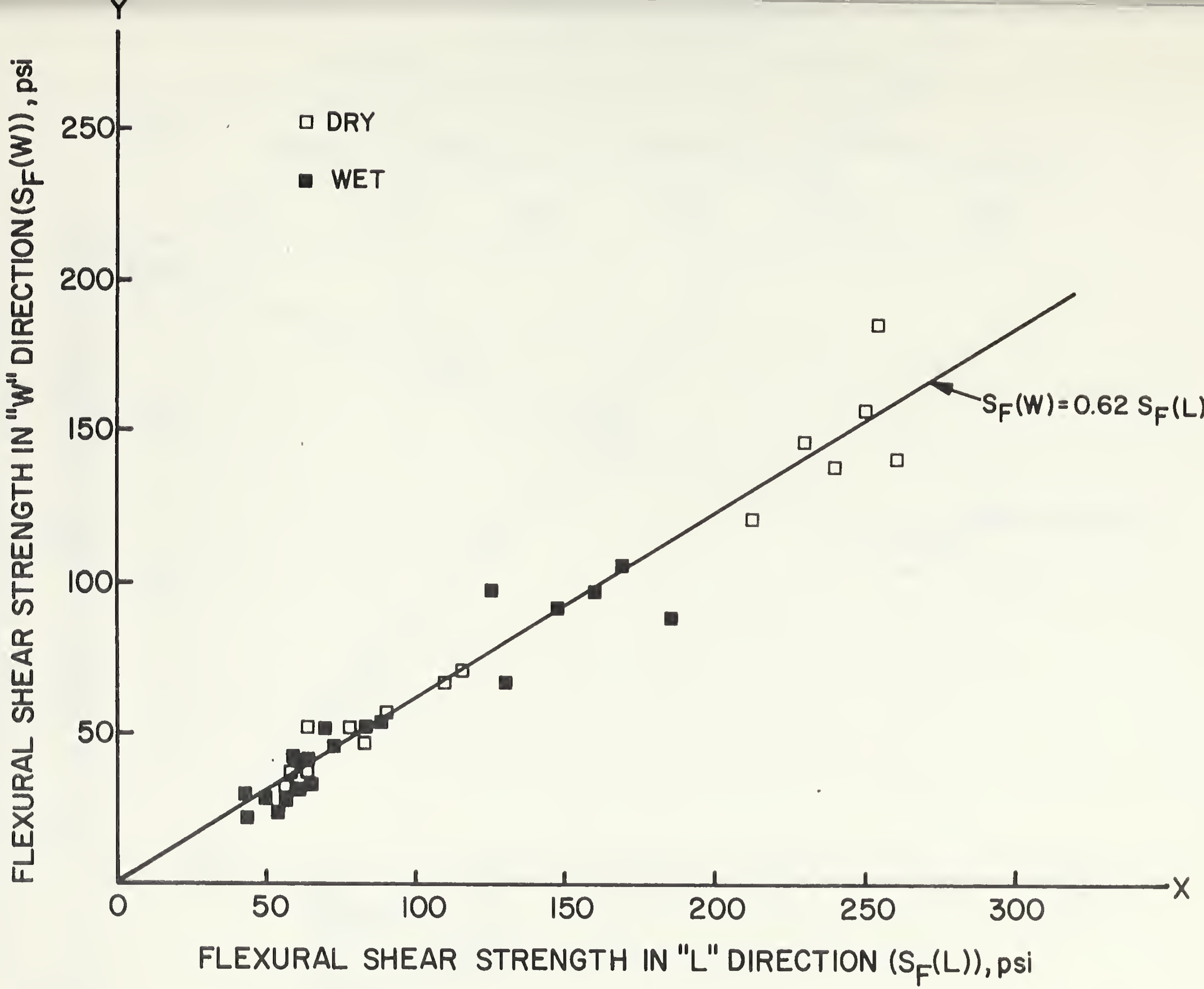

Figure 9. Flexural shear strength for all honeycombs except Brand D - "W" direction vs "L" direction.

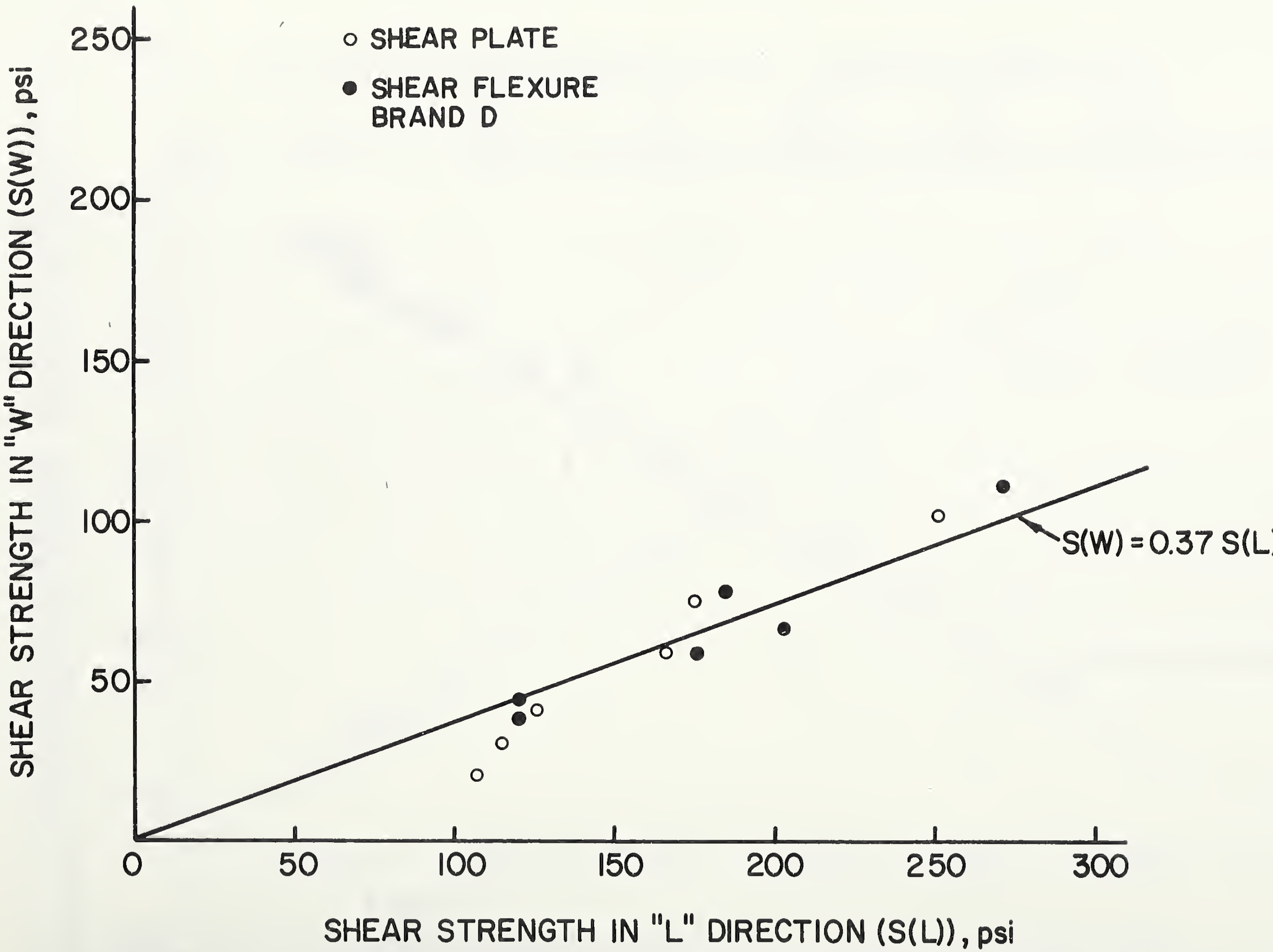

Figure 10. Plate and flexural shear strength for Brand D honeycomb - "W" direction vs "L" direction.

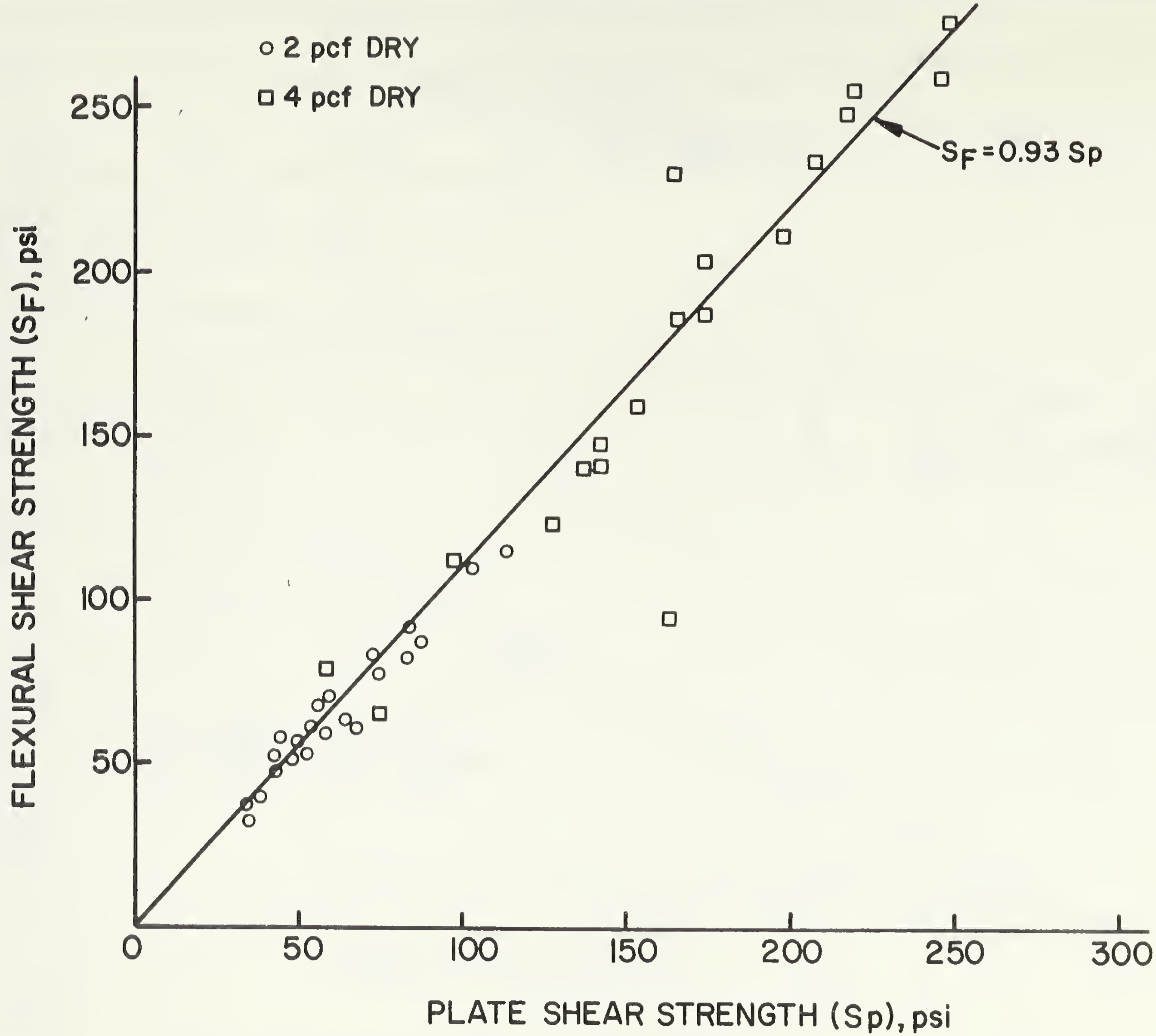

Figure 11. Flexural shear strength vs plate shear strength for all honeycombs.

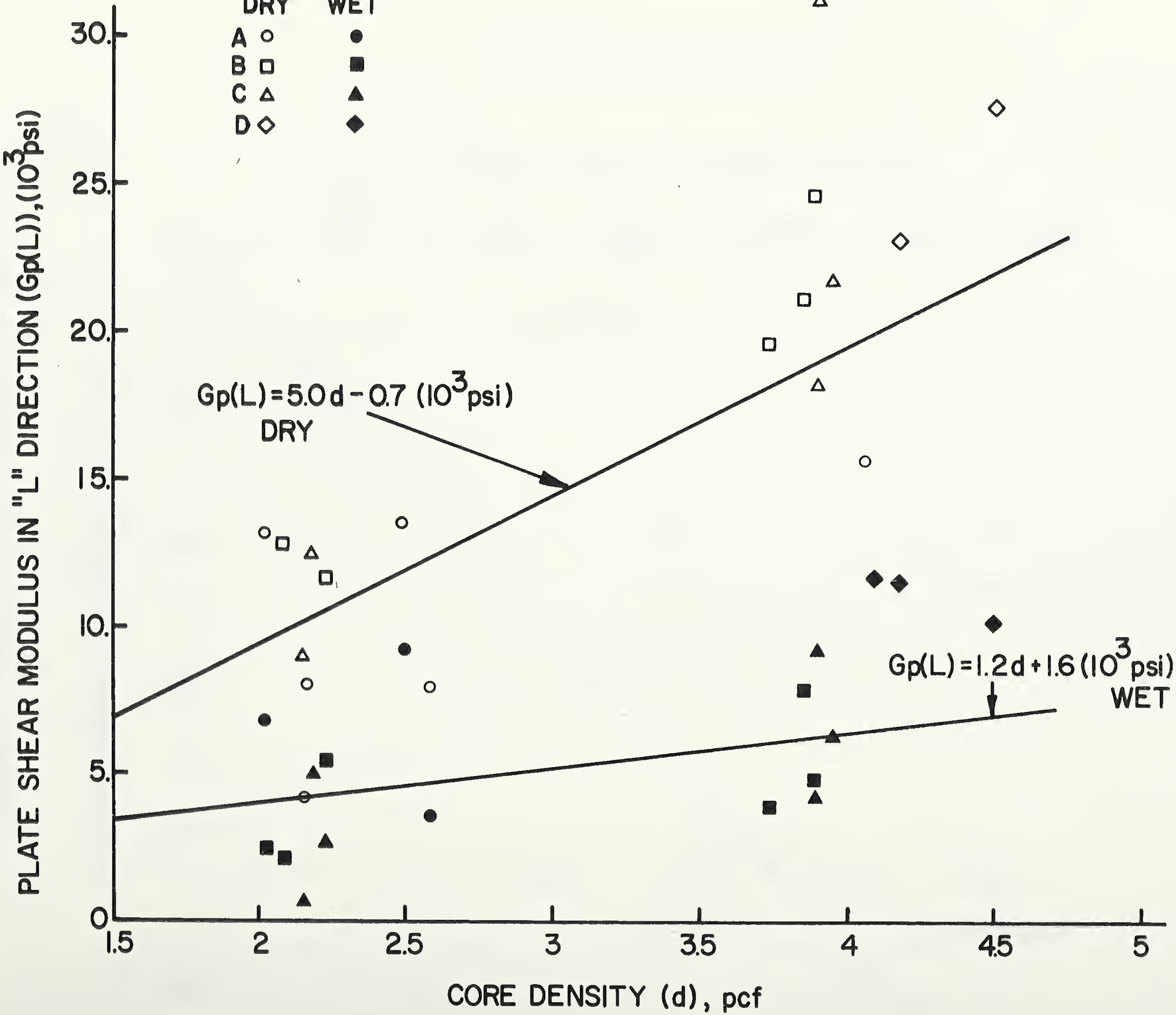

Figure 12. Plate shear modulus vs density for all honeycombs.

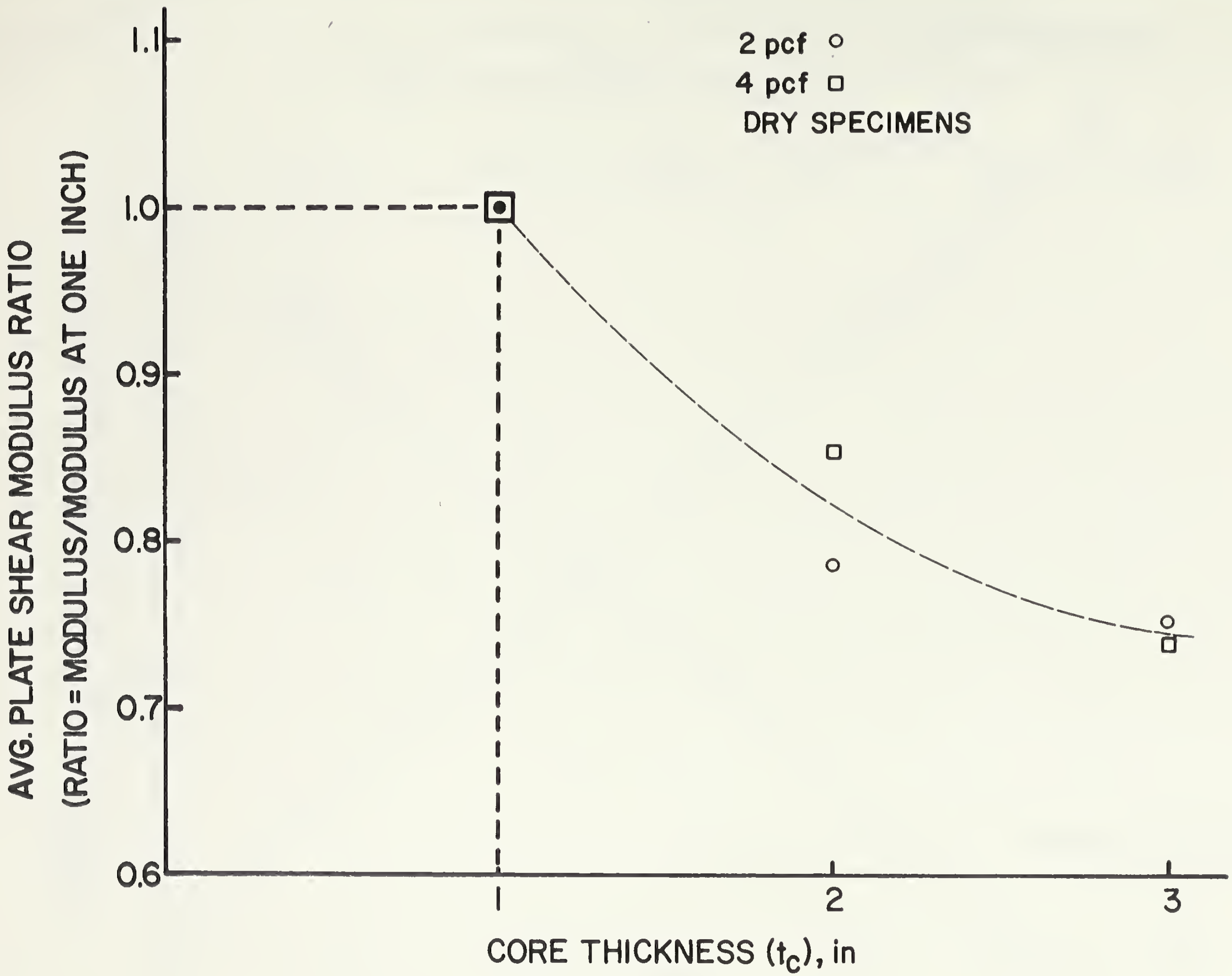

Figure 13. Effect of core thickness on plate shear modulus for all honeycombs.

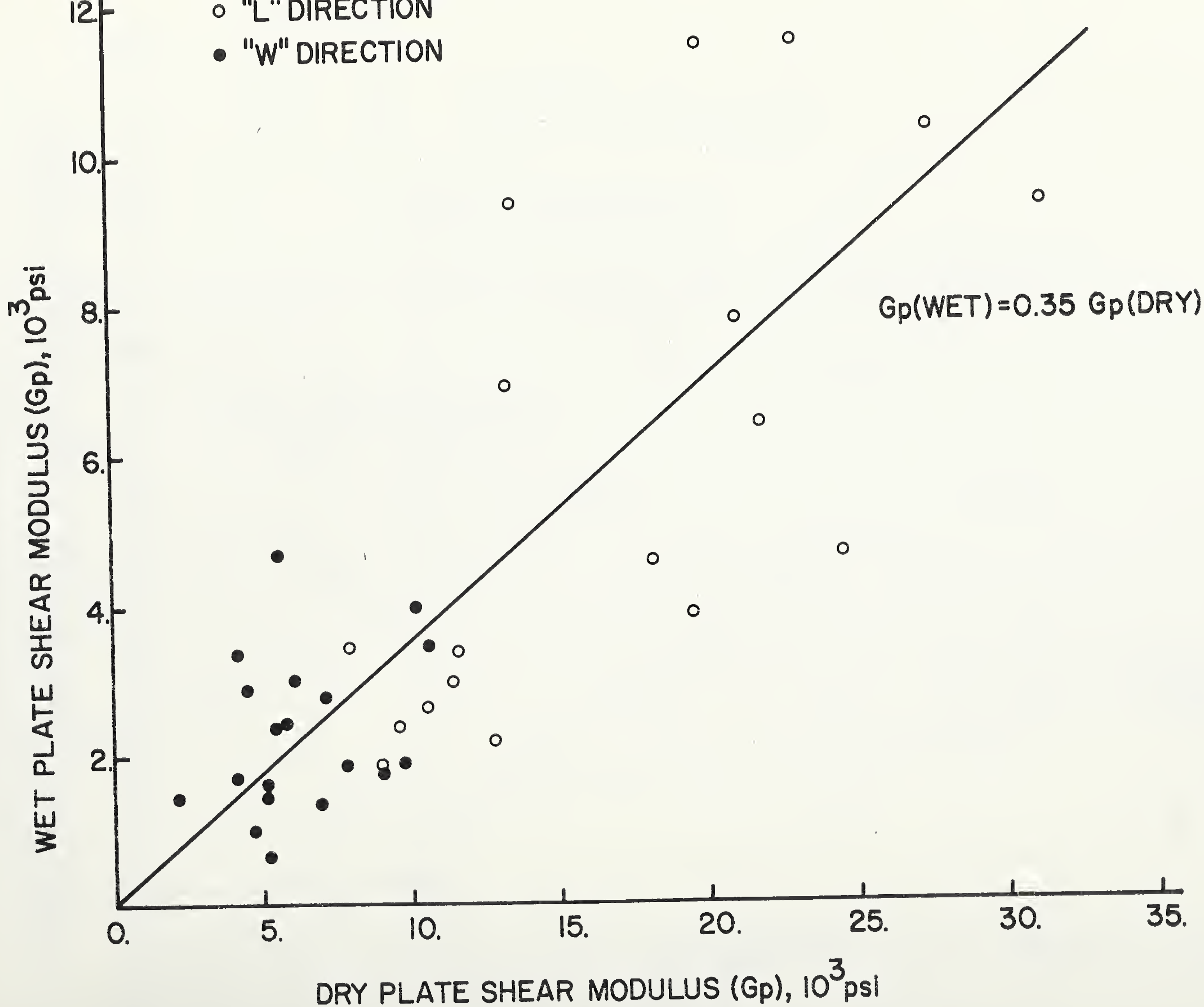

Figure 14. *Wet plate shear modulus vs dry plate shear modulus for all honeycombs.*

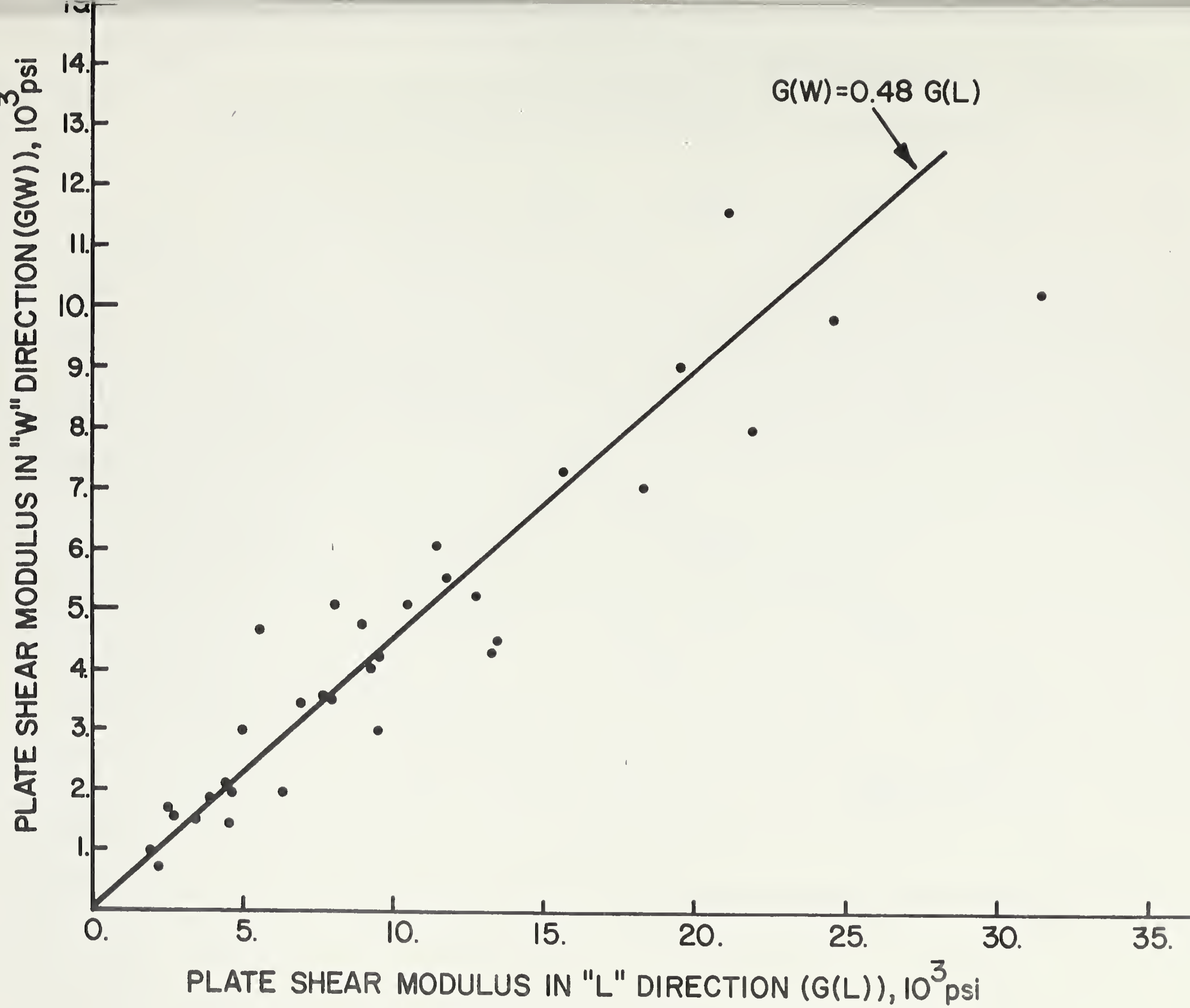

Figure 15. Plate shear modulus for all honeycombs except Brand D - "W" direction vs "L" direction.

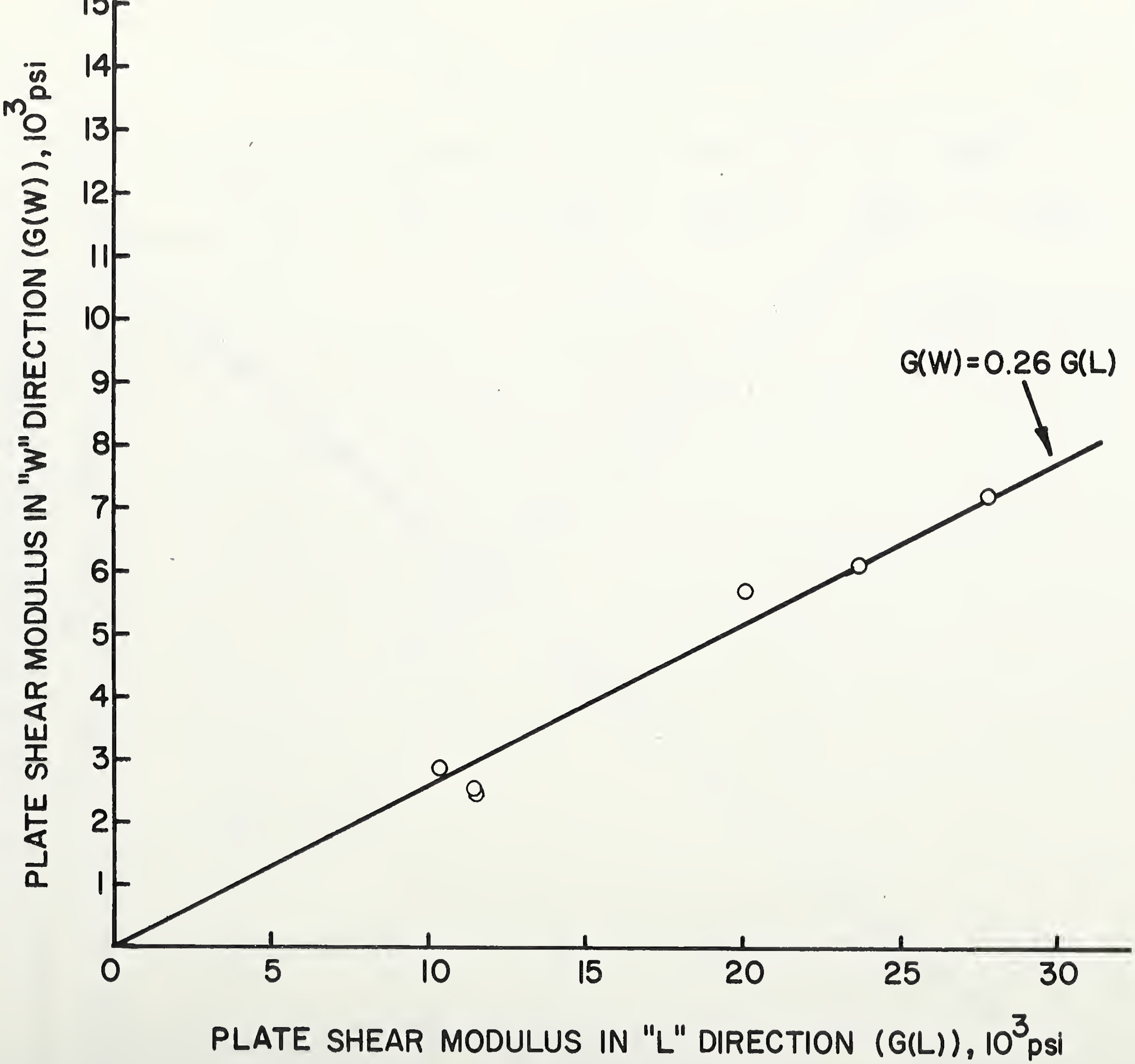

Figure 16. Plate shear modulus for Brand D honeycomb - "W" direction vs "L" direction.

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